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ON THE INTERPLANETARY SHOCK WAVES ASSOCIATED WITH SOLAR FLARES IN THE ACTIVE REGION McMATH No. 9740

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In this paper, we shall discuss the propagation pattern of shock waves emitted by solar flares which occurred successively in the active region McMath No. 9740 during 23 October to 4 November 1968. This pattern seems to be important for studying the propagation mechanism of these waves in interplanetary space.

This region was quite active for the production of solar proton flares (e.g., Sakurai, 1973a). These flares were associated with type II and IV radio bursts (Lincoln, 1970) and with SSC geomagnetic storms (Ballario, 1970). Table 1 summarizes these flares and associated phenomena. In this table, the transit times between the sun and the earth of the shock waves associated with the flares are shown and they give the mean speed of these waves in interplanetary space.

Using these transit times, we have examined the relationship between these times and the longitude positions of associated flares on the solar disk. Fig. 1 shows that these times are dependent on the positions of the flares and that the minimum of these times is reached ~45 degrees west of the central meridian plane of the solar disk. This result suggests that the speed of the shock wave emitted by a flare varies with the direction of the propagation. If we assume that the result shown in Fig. 1 expresses a mean pattern of the shock propagation, it follows that the shock wave does not propagate spherically nor symmetrically with respect to the meridian plane which crosses the position of an associated flare: that is, the shock wave is emitted into the direction some 10 degrees, say 45^{o}, east of this plane.

Since the result shown in Fig. 1 has been obtained in a series of solar-terrestrial events associated with the passage of one active region, we need some supporting evidence for the anisotropic propagation of shock waves such as shown in Fig. 1. We have statistically examined the time intervals between solar proton flares and SSC geomagnetic storms for the period 1956 - 1967. Fig. 2 shows the plots for these time intervals and the envelope for the minimum time intervals by a chain line. This envelope also indicates that the shortest transit time of these shock waves is reached when associated flares occurred about 30 degrees west of the central meridian of the solar disk.

The mean transit times for this statistical result also indicate that the minimum is reached when a solar flare occurrs in the region about 15 degrees west of the central meridian plane (Fig. 3) (Sakurai, 1973b).

Taking into account these results shown in Figs. 2 and 3, we can conclude that Fig. 1 indicates the speed of shock wave propagation is dependent on the position of an associated flare. Using the result shown in Fig. 1, we can, therefore, estimate the mean speeds of shock waves as a function of the direction of their propagation. Table 2 summarizes the mean speeds estimated from the transit times of shock waves. This speed is shortest for the flare at 0820 UT on 1 November 1968. We may use these mean speeds to estimate a gross feature of the shock wave propagation near the earth's orbit. A polar diagram for these speeds referred to the flare position is shown in Fig. 4. Although this figure does not seem to represent the shape of the shock wave just after emission from the sun, it seems very likely that the original shape of shock waves from solar flares is not quite different from that shown in this figure, and so not spherically symmetric with respect to the meridian plane which crosses the flare position. This suggests that these waves are emitted into the direction a few 10 degrees or more east of this meridian plane. This type of the propagation pattern is consistent with the results which have been obtained by Ness et al. (1969), Mariani et al. (1970) and Lepping et al. (1972). These people used interplanetary magnetic data obtained by several satellites to deduce the pattern of shock waves near the earth's orbit.

The pattern of shock wave propagation seems to form under the influence of the magnetic fields near flare region and in interplanetary space. Recently, Dulk et al. (1971) have shown that shock waves emitted by flares tend to propagate along the magnetic field lines near and above the regions where these flares occur. It seems, furthermore, that, after ejection from the sun, these waves are also well guided by the magnetic field lines in interplanetary space. The results shown in Figs. 1 and 4 are explained by taking into account the field-aligned propagation of shock waves in this space. Moreover, solar Mev protons and Kev electrons showed their field-aligned propagation in this space

(Sakurai, 1973a). The result obtained in this paper indicates that the interplanetary magnetic field controls the propagation of shock waves emitted by solar flares. Furthermore, this result suggests that the large-scale configuration of the interplanetary magnetic field was not disturbed by the successive propagation of the shock waves emitted by flares which occurred in the active region McMath No. 9740, and that these shock waves were rather well guided by this magnetic field in propagating in interplanetary space.

In conclusion, I would like to thank Drs. J.K. Chao and R.P. Lepping for their helpful suggestions.

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TABLE 1

SOLAR FLARES AND ASSOCIATED PHENOMENA

Time			Flare Position	Imp.	SSC Storm Transit Time (Hours)
Oct	27	1235	S16E18	1B	-
		1318	S17E18	2N	50.5
	29	1216	S16W12	1B	52
		1515	S14W19	(-N)	52
	30	1334	S18W28	2N	48
		2339	S14W37	3B	46
	31	2232	S15W49	2N	47
Nov	1	0820	S17W47	2B	41
	2	0601	S20W58	2N	52
		0949	S14W66	2B	51
	4	0520	S15W90	2B	63

TABLE 2

MEAN SPEED OF SHOCK WAVES IN INTERPLANETARY SPACE

Longitude Position of Flare (degrees)	Mean Speed of Shock Wave ($Kmsec^{-1}$)
E18	8.24×10^2
W12, W19	8.15×10^2
W28	8.7×10^2
W37	9.05×10^2
W47	1.48×10^3
W49	8.83×10^2
W58	8.15×10^2
W66	8.24×10^2
W90	6.6×10^2

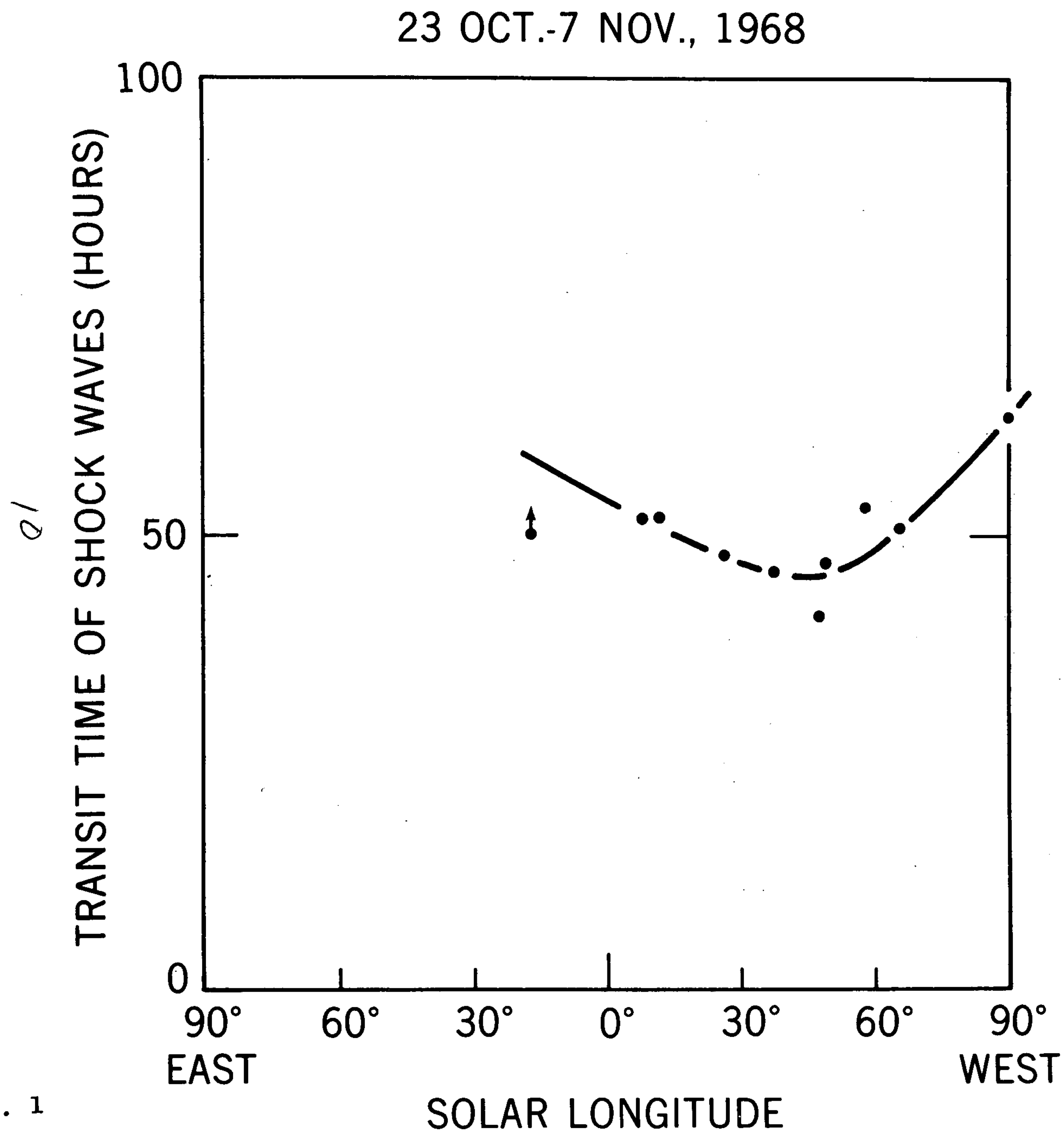
Caption of Figures

Fig. 1 - Solar longitude dependence of the transit times between the sun and the earth of shock waves emitted by solar flares during Oct. 23 to 4 November 1968.

Fig. 2 - The transit times between the sun and the earth of shock waves associated with proton flares (period from 1956 to 1967). A chain lines indicates the envelope for minimum time intervals.

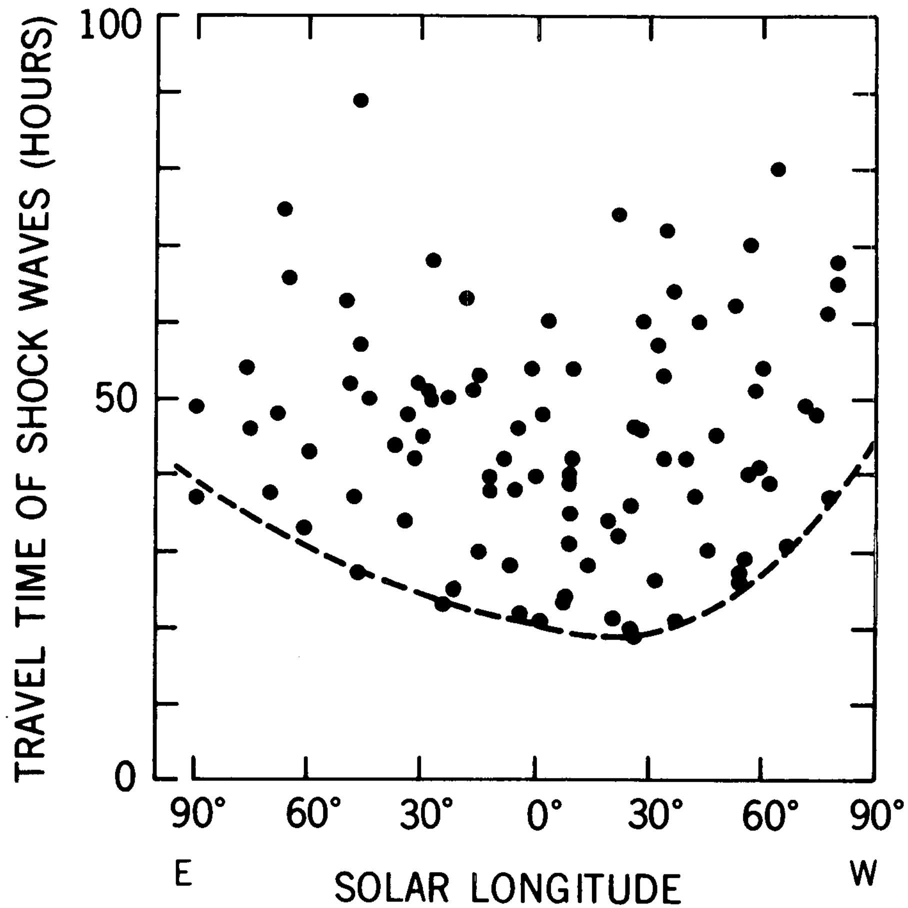
Fig. 3 - The mean transit times obtained from the result shown in Fig. 2.

Fig. 4 - Shape of the shock front near the earth's orbit. This is derived from the result shown in Fig. 1.



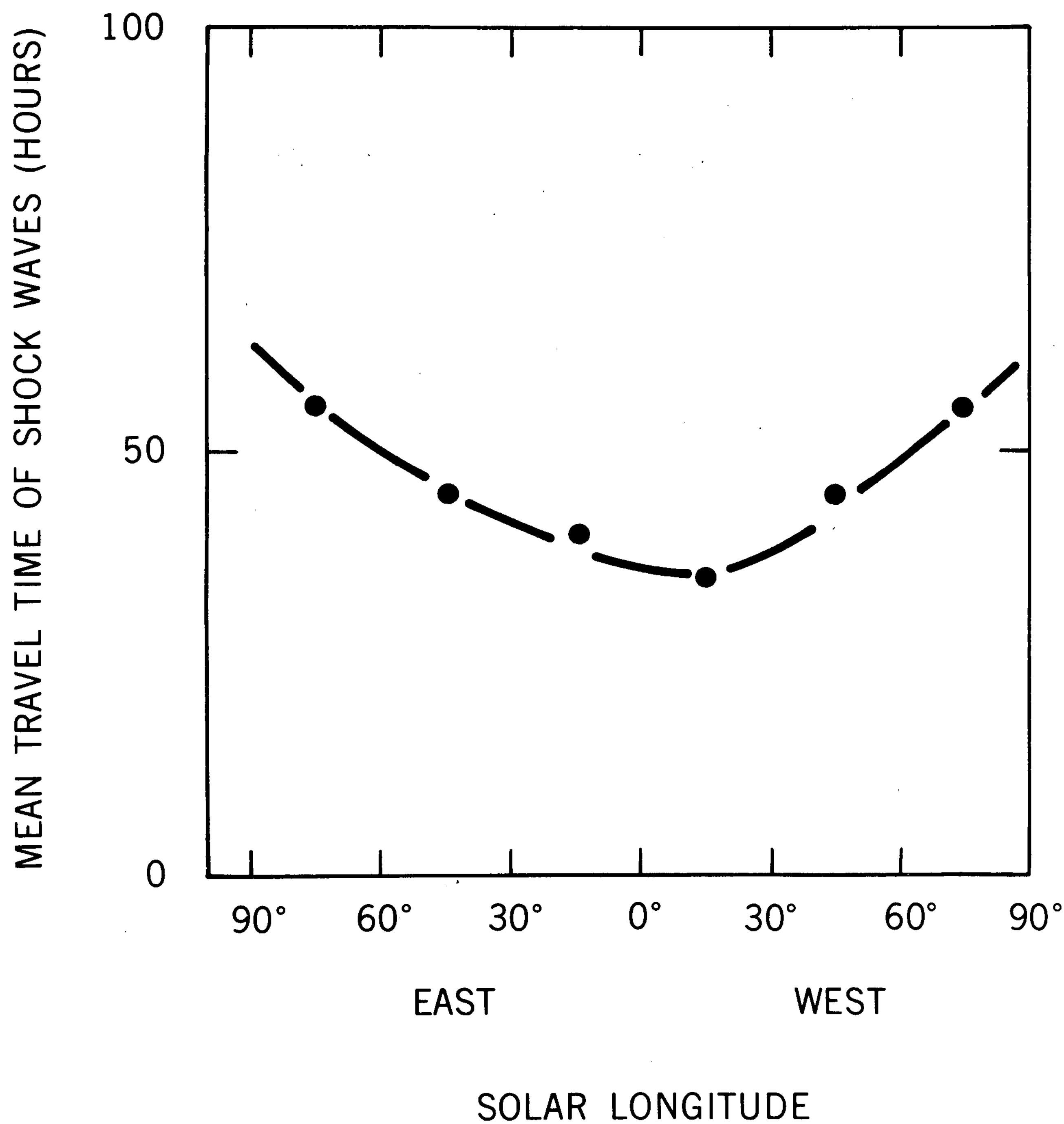
23 OCT.-7 NOV., 1968
TRANSIT TIME OF SHOCK WAVES (HOURS)
100
50
0
90°
EAST
60°
30°
0°
30°
60°
90°
WEST
SOLAR LONGITUDE

Fig. 1



TRAVEL TIME OF SHOCK WAVES (HOURS)
100
50
0
90°
60°
30°
0°
30°
60°
90°
E
SOLAR LONGITUDE
W

Fig. 2



MEAN TRAVEL TIME OF SHOCK WAVES (HOURS)
100
50
0
90°
60°
30°
0°
30°
60°
90°
EAST
WEST
SOLAR LONGITUDE

Fig. 3

12

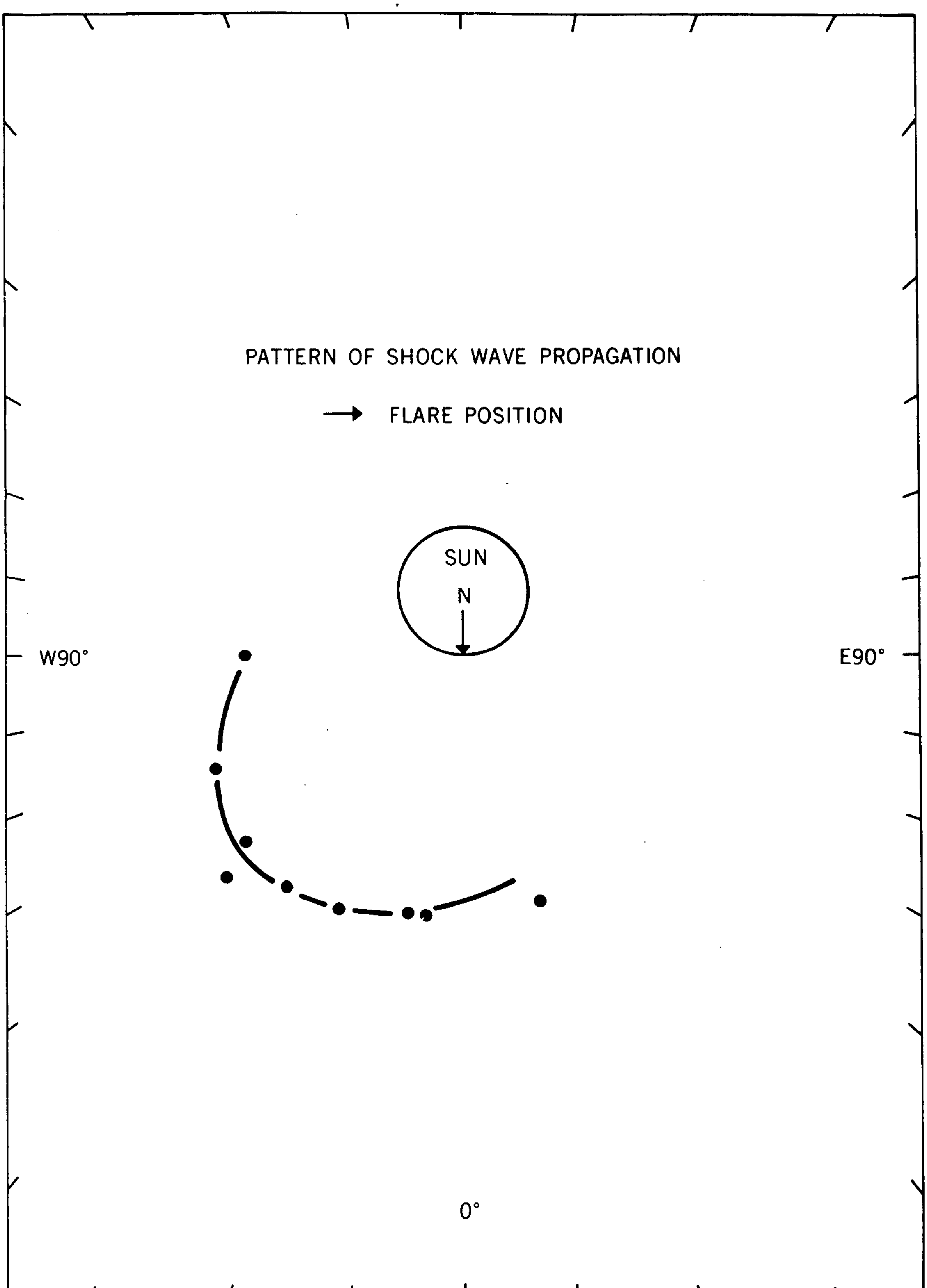


Fig. 4

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